Final Report

Competitive Analysis:
Levelized Cost of Electricity (LCOE)

Rev. E February 5, 2008

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Introduction

The Levelized Cost of Electricity (LCOE) is the principle metric by which electricity generation technologies are compared. This established basis for evaluating the cost of a generation method takes into account those aspects of a technologies performance that directly impact power generation efficiency, system cost, and reliability. LCOE is a measure of the total lifecycle costs associated with a PV system divided by the expected lifetime-energy output, while accounting for the appropriate adjustments such as time value of money, etc.

The National Renewable Energy Laboratory (NREL) has developed a robust model that considers the climatic variables which impact solar energy generation for hundreds of US locations called: the Solar Advisor Model (SAM). As a participant in the Solar America Initiative, IBIS Associates is expert in the use of the SAM software. In addition, IBIS has supported numerous government proposals by small and large PV Companies by providing the requisite LCOE benchmarking analyses.

Scope

As a manufacturer of a novel thin film Photovoltaic (PV) cell and module technology, XsunX requires a detailed, unbiased analysis of their competitive LCOE position relative to incumbent PV-technologies and immediate competing products. Five (5) key competing PV products have been chosen as the scope of this analysis; representing a diverse range of available and leading field-installation PV products.

- a-Si triple junction (e.g. ECD)
- mc-Si (Schott)
- CIGs (Global Solar)
- CdTe (First Solar)
- X-Si (Sharp)
- A-Si tandem junction (XsunX)

The technologies were chosen based on their prominence in the market (i.e. X-Si) and unique performance characteristics that make them uniquely competitive in the markets that XsunX intends to target (i.e. low light areas – a-Si tandem junction).

The scope of the analysis was further constrained to two (2) US locations that provide bases for evaluating the products in extreme temperature and irradiance conditions.

- Phoenix, AZ
- Portland, OR

The locations were also selected based on the availability of climate and environmental data (i.e. solar radiance, cloud coverage, temperature, etc.).

System Descriptions

Levelized Cost of Electricity (LCOE) analyses are calculated based on simulations of products and systems designs in specific locations. The module technologies under consideration may be configured in a wide range of stationary, tracking, rooftop or field installations. The choice of system design drives the Balance of System (BoS) requirements, land usage, maintenance and installation costs and performance (tracking).

The choice of system design was chosen as the choice of locations for the analyses were chosen; to profile the market segments for which XsunX's cell technology is best suited.

Cell Performance

Cell performance characteristics were collected from product specification sheets, academic literature, and NREL (testing) publications.

XsunX

XsunX, Inc. has developed a novel thin film solar Photovoltaic (PV) cell technology is comprised of ***tandem junction amorphous silicon layers (a-Si tandem junction)***.

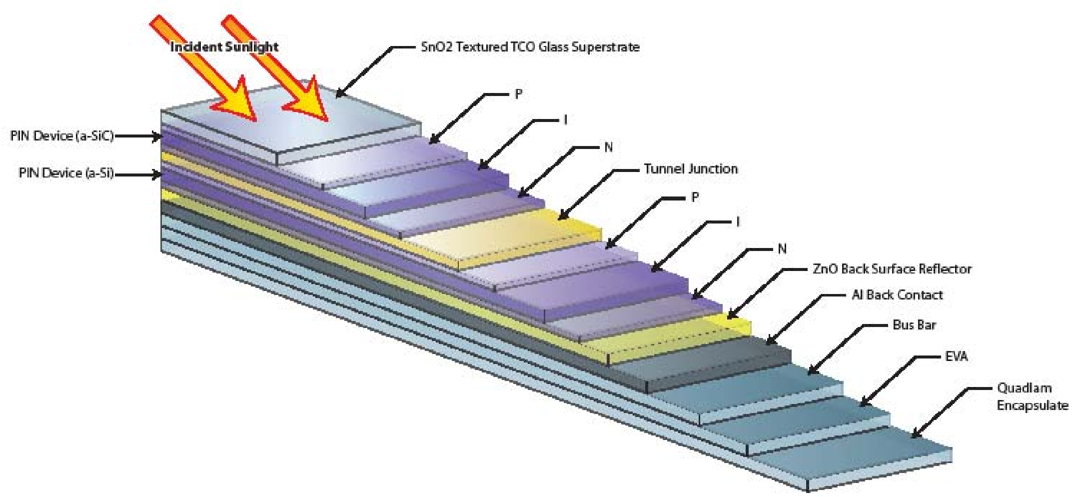

Figure 1 – XsunX, Inc. Solar PV Cell Schematic

Due to its novel material structure, the technology has several key performance attributes that make it cost competitive in low light and high temperature conditions. Early morning and late afternoon solar irradiance generally provides light consists of a shorter wavelength. Based on the photo-absorbent material components in each cell, performance during early and late day time periods will vary. It has been found that the improved low light performance of amorphous silicon, which is contained in both the "a-Si Triple Junction" product and the XsunX cell improves overall cell output by approximately 20%[1].

Although amorphous silicon solar cells suffer from lower conversion efficiency under Standard Test Conditions (STC), it has been found that the performance of this type of solar photovoltaic cell technology is outstanding in low light (diffuse) conditions. As a result, under non-ideal conditions amorphous silicon solar cells can outperform crystalline cell products.

Non-ideal conditions, for which amorphous silicon cells are particularly well suited, include non-ideal orientations and low light conditions. The Pacific Northwest, Portland, Oregon for instance is typically not thought to be an area where solar photovoltaics are viable. The amount of cloud cover (diffuse light) is on average, quite high. However, every location, no matter how well suited they appear for solar electricity generation, suffers some losses early in the morning and late in the afternoon.

Product	Temp Coefficient / °C	Source
mc-Si	-0.47%	Schott litterature
a-Si (Triple Junct)	-0.31%	NREL
CIGS	-0.60%	Shell litterature
CdTe	-0.20%	First Solar litterature
X-Si	-0.47%	Schott litterature
a- Si (Tandem Junct)	0.00%	Sanyo brochure (a-Si)

Table 1 – Temperature coefficients by technology

The power density (DC peak) of the product is approximately 78.75 $W_{DC\ peak}$ / m^2 (fourth highest among the six products investigated in this analysis).

[1] "Triple Junction Thin Film Silicon Solar Cells compared to Crystalline Silicon Solar Cells under Real Outdoor Conditions in Western Europe", Cleef et al, Bekaert ECD Solar Systems Europe N.V.- BESS EUROPE, Zulte, Belgium, 2001

Product	Power Density $W_{DC\ peak} / m^2$	Suitability for area constrained Applications
X-Si	133.00	High
mc-Si	123.60	↑
CIGS	81.46	↕
a- Si (Tandem Junct)	75.84	↕
CdTe	72.39	↓
a-Si (Triple Junct)	60.09	Low

Table 2 – Suitability for rooftop installations (product power densities)

System Type: Field Installation

The relatively low XsunX cell power density however makes that product most suitable for installations where space is not limited (i.e. non-rooftop or field installation applications). While rooftop applications are a key market that XsunX, Inc. is targeting, especially in niche markets, such as low light and high heat climates, field installations are most likely to make up the majority of the XsunX's early adopters.

Competing Modules: Cell Performance

The performance characteristics of the competing cell and module technologies was collected from first hand (i.e. manufacturers, solar integrators), as well as through public literature.

Performance Characteristics		mc-Si	a-Si (Triple Junction)	CIGS	CdTe	X-Si	a-Si (Tandem Junction)
Short Circuit Current (Isc)	A	6.5	5.1	4.1	1.066	8.35	1.5
Open Circuit Voltage (Voc)	V	60	46.2	52	79.58	36.3	58
Maximum Power Point Current (Impp)	A	5.9	4.1	3.24	0.918	7.53	1.27
Maximum Power Point Voltage (Vmpp)	V	51	33	37	56.78	28.71	100
Inverter power rating	Wdc/inverter	333,000	333,000	333,000	333,000	333,000	333,000
Module efficiency	%	12.36%	6.26%	8.16%	7.24%	12.60%	7.90%
System degradation	% / year	0.25%	0.25%	0.25%	0.25%	0.25%	0.25%
Module lifetime	years	20	20	20	20	25	20

Table 3 – Cell Performance Characteristics

In the case of system degradation, reliable data was not readily available for all products. As a result, a constant was chosen for all module technologies. This represents an area where greater resolution is likely to become available as longitudinal data becomes available from aging installations (experience).

System size

The baseline system size considered was chosen to represent a “large” (e.g. power purchase or utility) installation; 1MW (AC peak power/year).

Module Price: Volume Discounts

In addition to directly impacting the investment requirements for items such as BoS components, racks, and installation labor, system size also directly impacts module price. Discounts to retail module prices are often offered to customers making large purchases.

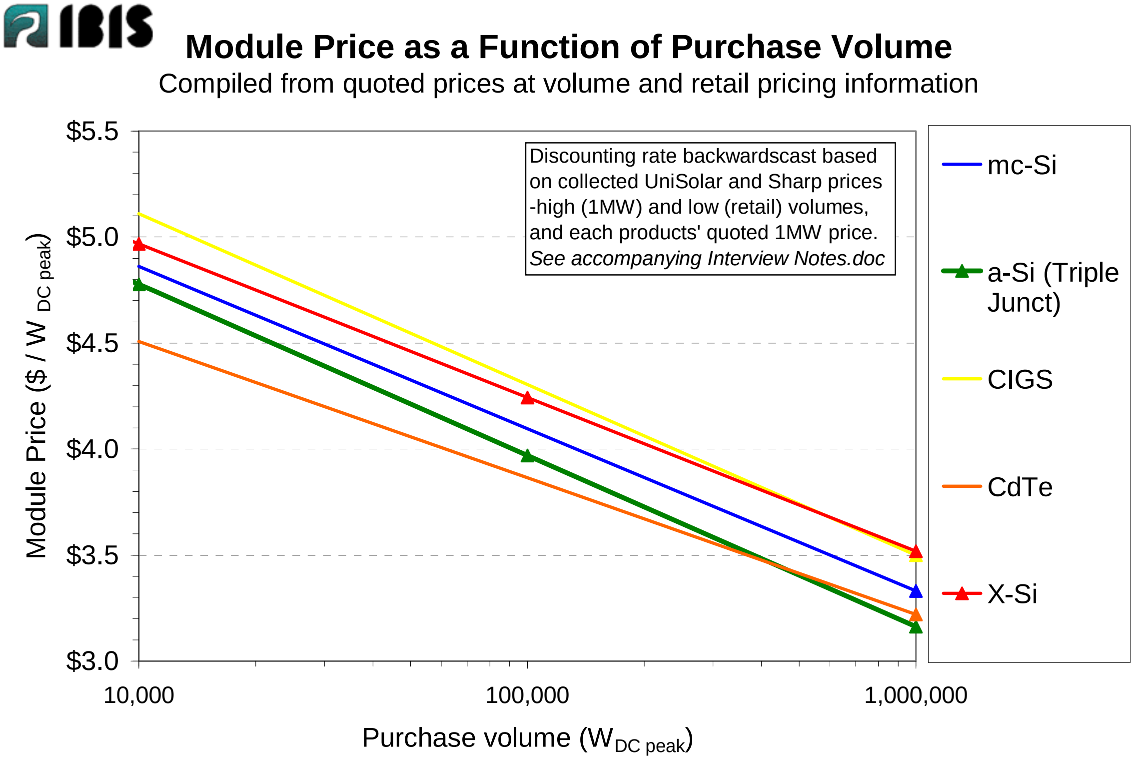

Figure 2 – Module Price as a Function of Purchase Volume

High volume module prices were collected for each technology of interest. In case of two of the five products multiple data points were collected describing the volume price discount available. These relationships were used to back-cast the lower volume purchase price for the remaining three products, based on the discount rate and known high volume (1MW $_{\text{DC peak}}$) purchase price for each.

Installation Land Requirements

Whether the non-rooftop field installation is being installed for a utility or commercial Power Purchase Agreement (PPA), the end user is most likely to determine the system ‘size’ based on power generation (AC Watts). Differences exist among the technologies of interest, in terms of the power density ($W_{DC\ peak} / m^2$) they provide. In addition, the performance of each module also varies.

General system derate factors were held constant for the purposes of this analysis. Soiling, AC and DC wiring, module mismatch, and diode losses have been held constant. Inverter conversion efficiency was also held constant for each module.

Derate Factor	Assumption
PV module nameplate DC rating	95%
Total DC/AC inverter efficiency	94.50%
Mismatch	98%
Diodes and connections	96.0%
DC wiring	97.5%
AC wiring	97.5%
Soiling	100%
System availabilty	100%
Shading	100%
Sun-tracking	100%
Age	100%

Table 4 – System Derate Factors: Model Assumptions (Input Variables)

Additionally, the temperature coefficients (see Table 1 in the above section) and climate variables (hours and intensity of solar irradiance) contribute to the amount of power provided by each module technology. The number of modules required to achieve the minimum AC power output given each system's derate and conversion performance factors was calculated for each module technology.

The baseline analysis was conducted around a 1 MW fixed field installation. The tilt was calculated to be equivalent with that of the location's latitude, in order to maximize the performance during the entire year. Land usage is calculated based on the number of modules required to provide the minimum power requirement, footprint of each module, and minimum spacing to accommodate the maximum shadowing affect between each row, given the tilt angle.

Portland, Oregon is located at latitude 45.5 degrees North.

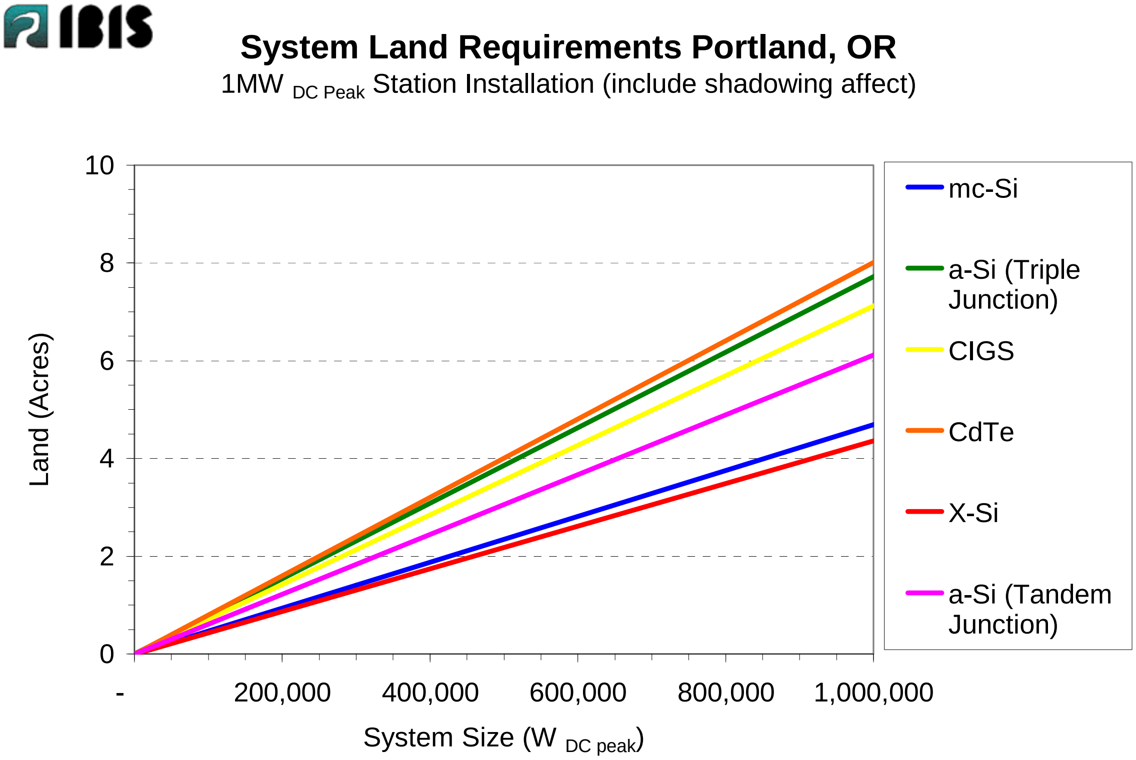

Figure 3 – Land Usage Requirements: Portland, OR

Phoenix, Arizona is located at latitude 35.5 degrees North.

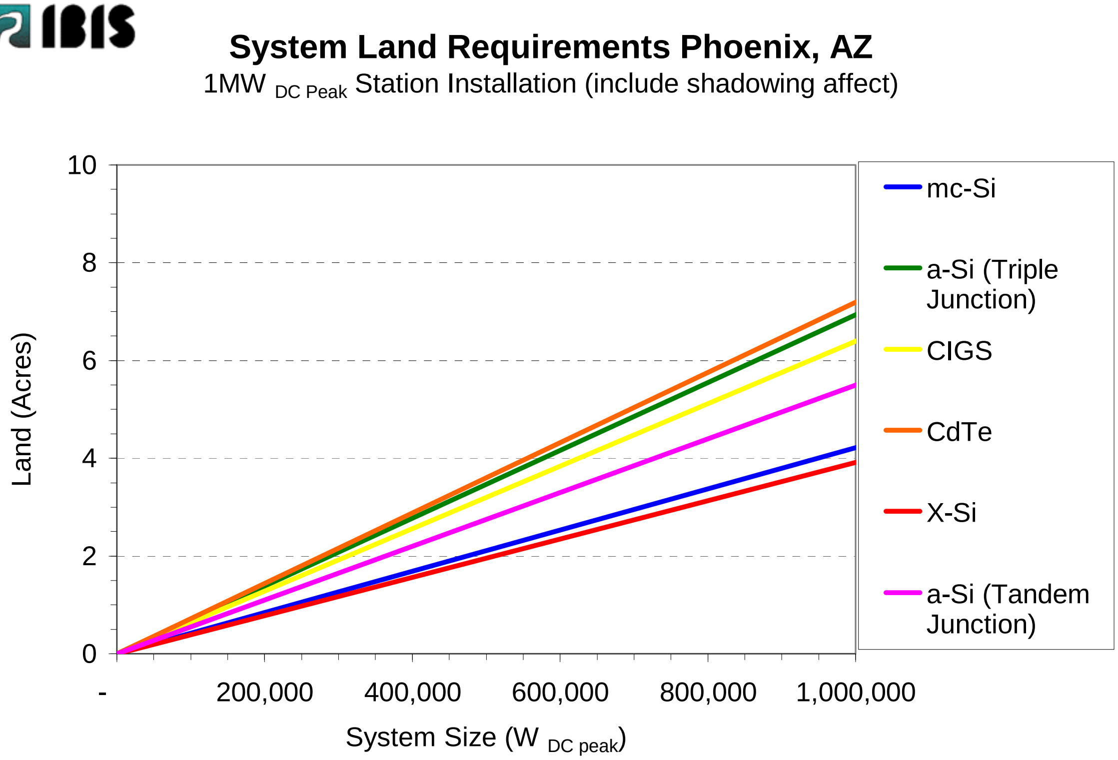

Figure 4 – Land Usage Requirements: Phoenix, AZ

The difference in available solar resources between the locations of interest; Portland, Oregon and Phoenix, Arizona, as well as the module performance differences in these conditions, and latitude (tilt) of the cells account for the difference in land requirements between the regional installations.

Balance of System Costs

The Balance of System costs associated with each module's installation design is directly related to the size of the installation; number of modules and module size (land requirements, and weight).

Relative System Size - Phoenix, AZ (1MW AC)

	mc-Si	a-Si (Triple Junction)	CIGS	CdTe	X-Si	a-Si (Tandem Junction)
Area	1.00	1.65	1.52	1.71	0.93	1.30
# modules	1.0	1.85	2.50	5.75	1.38	1.98

Table 5 – Relative System Sizes: Phoenix, AZ

Relative System Size - Portland, OR (1MW AC)

	mc-Si	a-Si (Triple Junction)	CIGS	CdTe	X-Si	a-Si (Tandem Junction)
Area	1.00	1.65	1.52	1.71	0.93	1.30
# modules	1.0	1.85	2.50	5.75	1.38	1.98

Table 6 – Relative System Sizes: Portland, OR

The cost of balance of system components was estimated by a number of solar integrators and module providers (see Appendix: Interview Notes). This data was supplemented with academic publications and information from the public domain[2].

The model has the capacity to predict the balance of system costs based on the installation size. The amount (cost) of "long wiring" and "conduit" scales as the land requirements scale. The cost of "cable housing, fuse boxes, connectors" and "connection wiring" (between modules) scales with the number of modules that are required to achieve the predetermined annual power output.

Inverters

Inverter costs, lifetime, and size were chosen based on conversations with solar integrators who have experience installing 1MW field systems.

- Advanced Energy Industries: 333kW inverter, 94.5% efficiency
    - Monitoring and Data Acquisition: $4500 per inverter

The costs parameters and product performance was held constant across all module technologies.

[2] "Photovoltaic Power Plant Experience at Tucson Electric Power", Moore et al,

Results and Analysis

Phoenix, Arizona and Portland, Oregon were selected as the locations of the analyses because of the contrasting climatic conditions found in those areas. While Phoenix has a plenty of direct solar resources, as a result the cell temperatures are elevated. In Portland there are far less solar resources available (i.e. diffuse light as a result of significant cloud cover), but the cell temperatures are much more moderate.

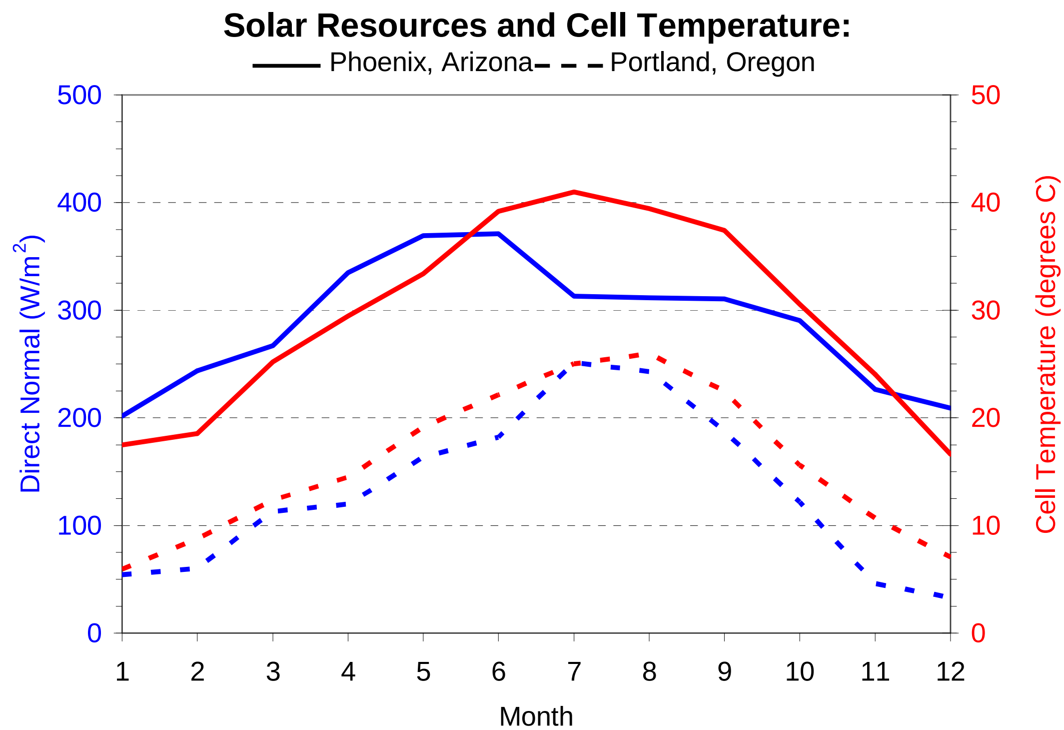

Figure 5 – Resulting Solar Resources and Cell Temperatures: Phoenix, AZ and Portland, OR

Phoenix, AZ

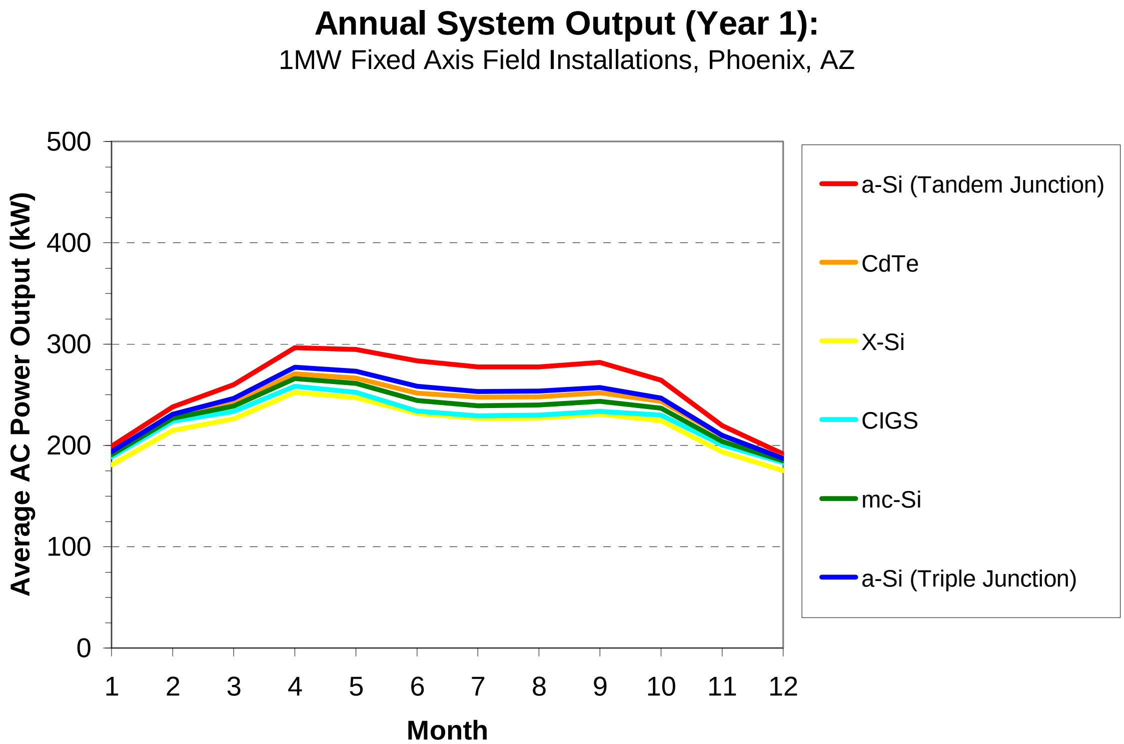

Figure 6 – Annual Output: 1MW, Phoenix, AZ (fixed axis)

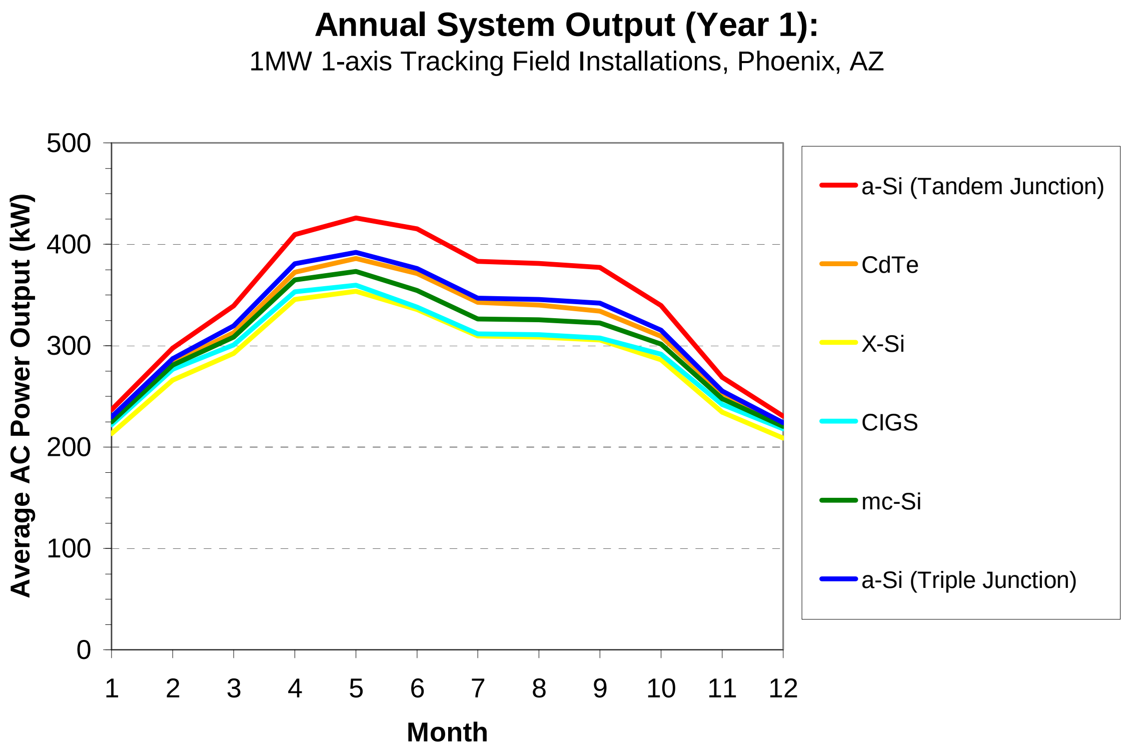

Figure 7 - Annual Output: 1MW, Phoenix, AZ (1-axis)

A 1-axis tracking system increases the power output of the systems by approximately 33%.

1MW Field Installation, Annual Output (Phoenix, AZ)

	a-Si (Tandem Junction)	CdTe	X-Si	CIGS	mc-Si	a-Si (Triple Junction)
tracking benefit	33.1%	32.1%	31.5%	31.0%	31.5%	32.1%

Table 7 – Impact of 1-axis tracking on Phoenix, AZ installations

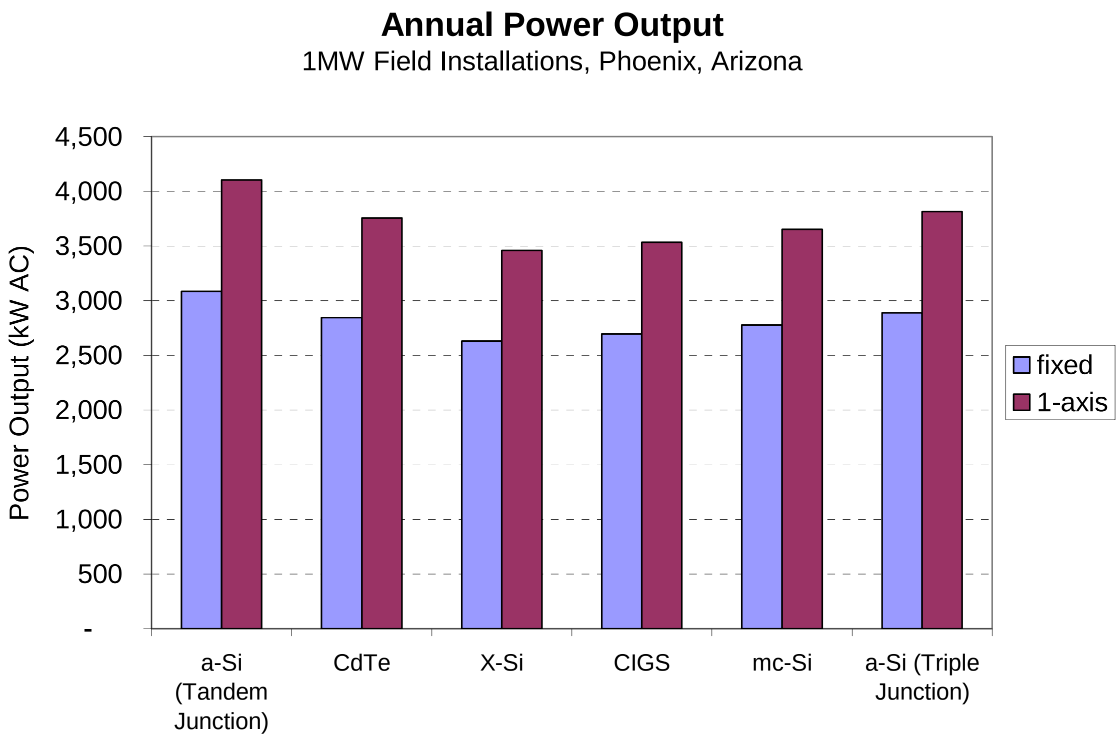

Figure 8 – Annual Power Output: Phoenix, Arizona

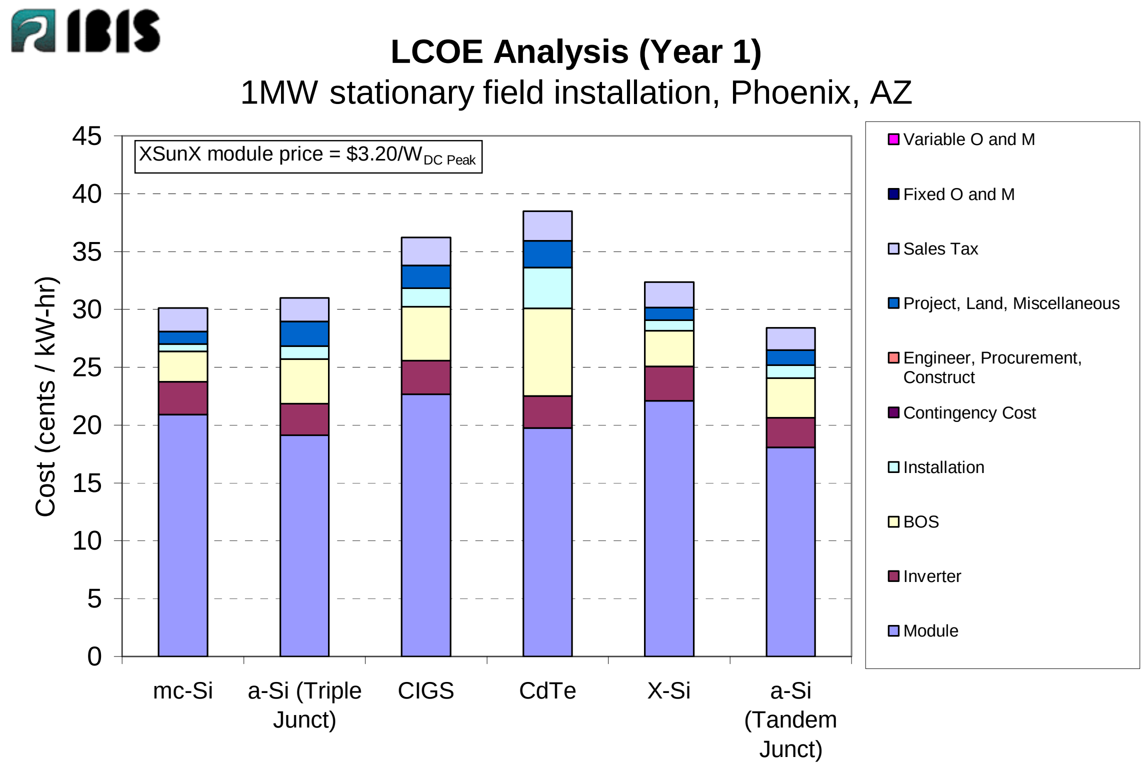

Figure 9 - LCOE: 1MW Phoenix, AZ (fixed axis), $3.20/W XsunX module price

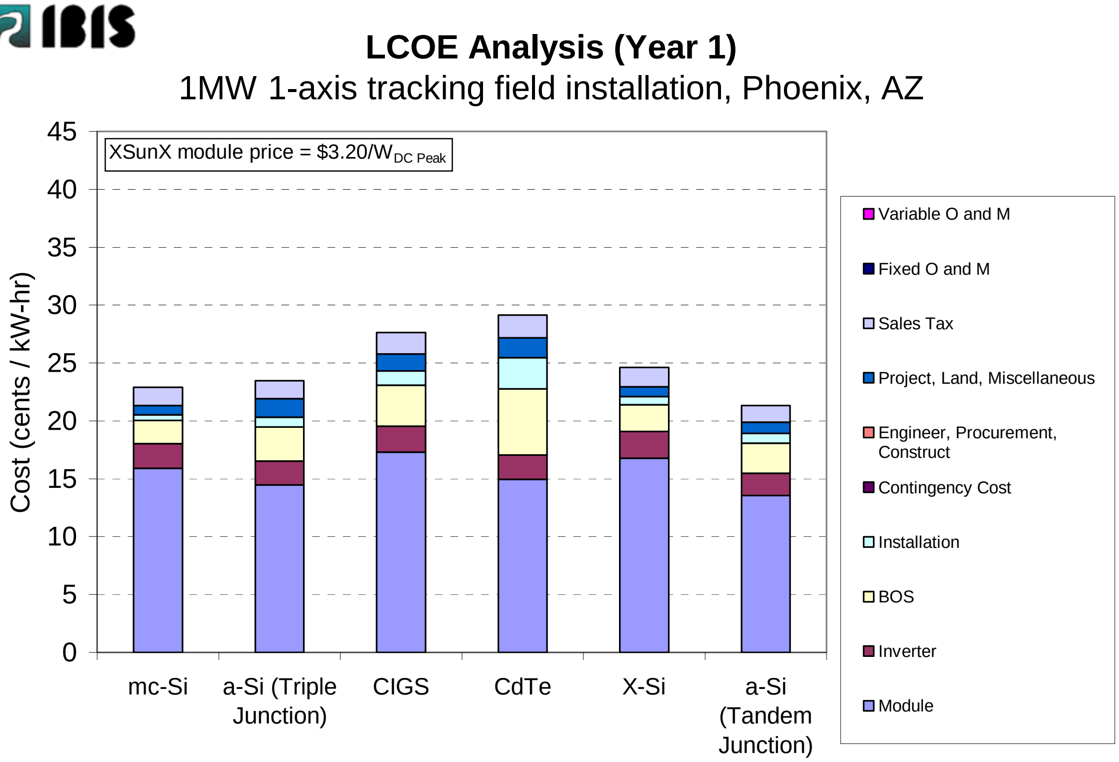

Figure 10 - LCOE: 1MW Phoenix, AZ (1-axis tracking), $3.20/W XsunX module price

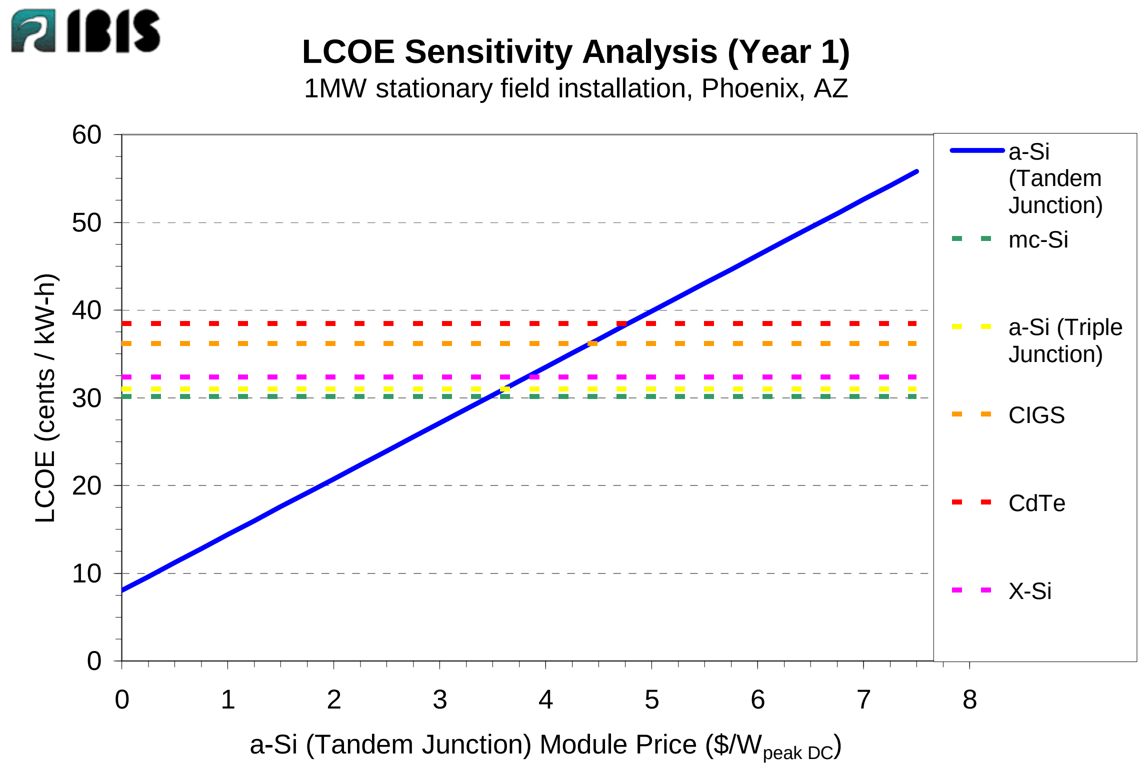

Figure 11 – LCOE Sensitivity: XsunX module price, 1 MW Phoenix, AZ (fixed axis)

The model utilizes a bottoms-up approach to quantifying the Levelized Cost of Electricity (LCOE). Because of this approach it is possible to conduct parametric sensitivity analyses, assessing the impact of changes to independent variables on the LCOE results. It is useful, for instance to assess the impact of ***a-Si (Tandem Junction)*** module price on the analysis because of the relative uncertainty associated with this variable. XsunX has a business plan which includes a product price based on detailed cost model and analysis. A number of uncertainties may contribute to the price either rising or falling (e.g. gas prices).

To read Figure 11 above, consider the analyses of all of the technologies to be static across the variable ("Module Price") except ***a-Si (Tandem Junction)***. The a-Si Tandem Junction technology is the focus of the parametric analysis. The x-axis provides a range of module prices. The y-axis shows the resulting LCOE for the a-Si Tandem Junction at each of these module prices. The cross over points show the a-Si (Tandem Junction) module prices that result in equivalent LCOE figure to each competing technology. A-Si (Tandem Junction) is equivalent in LCO costs to mc-Si at a module price of ~$3.50/$W_{peak\ DC}$ and equivalent to the system based on the CdTe module at a price of ~$4.75/$W_{peak\ DC}$.

Portland, OR

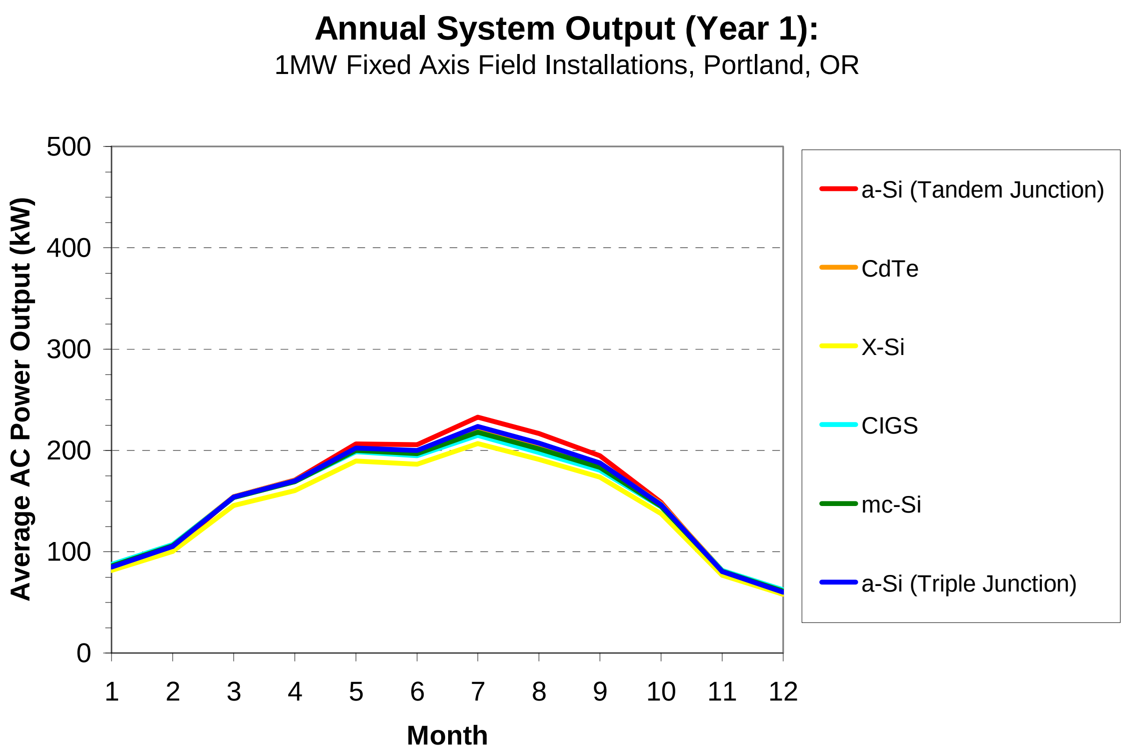

Figure 12 - Annual Output: 1MW, Portland, OR (fixed axis)

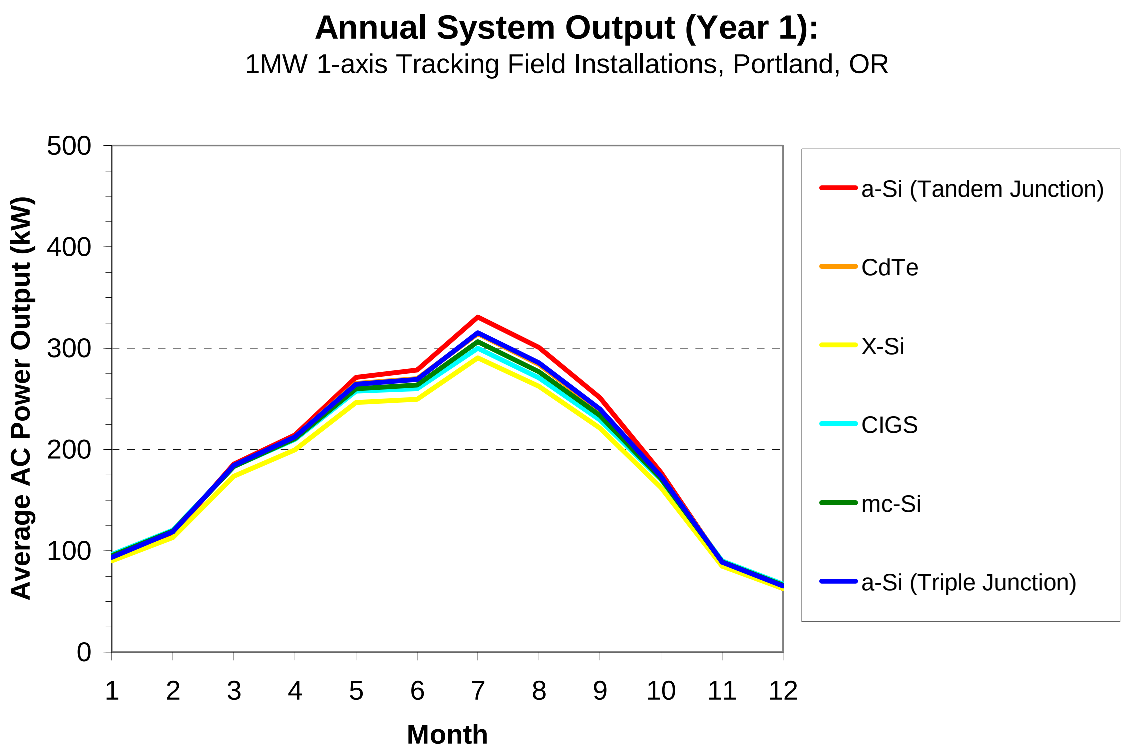

Figure 13 - Annual Output: 1MW, Portland, OR (1-axis)

The 1-axis tracking system provides a 28% performance benefit for the amorphous silicon tandem junction cells.

1MW Field Installation, Annual Output (Portland, OR)

	a-Si (Tandem Junction)	CdTe	X-Si	CIGS	mc-Si	a-Si (Triple Junction)
tracking benefit	27.8%	26.9%	26.3%	25.9%	26.3%	26.8%

Table 8 - Impact of 1-axis tracking on Portland, OR installations

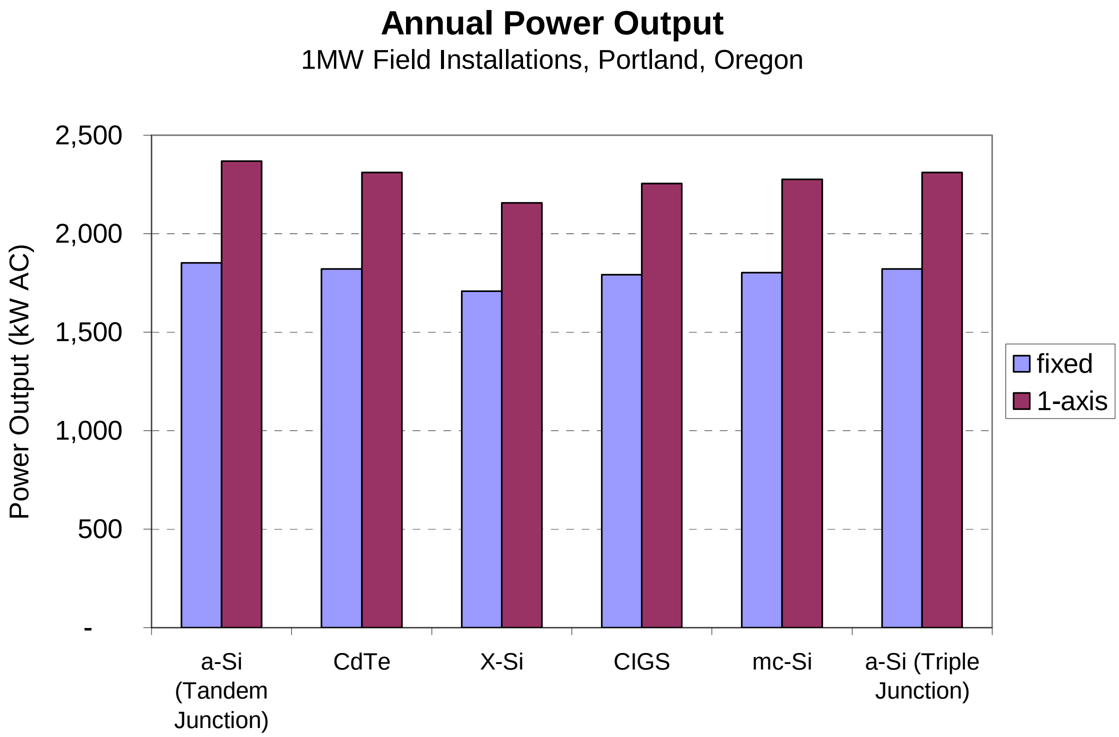

Figure 14 – Annual Power Output: Portland, Oregon

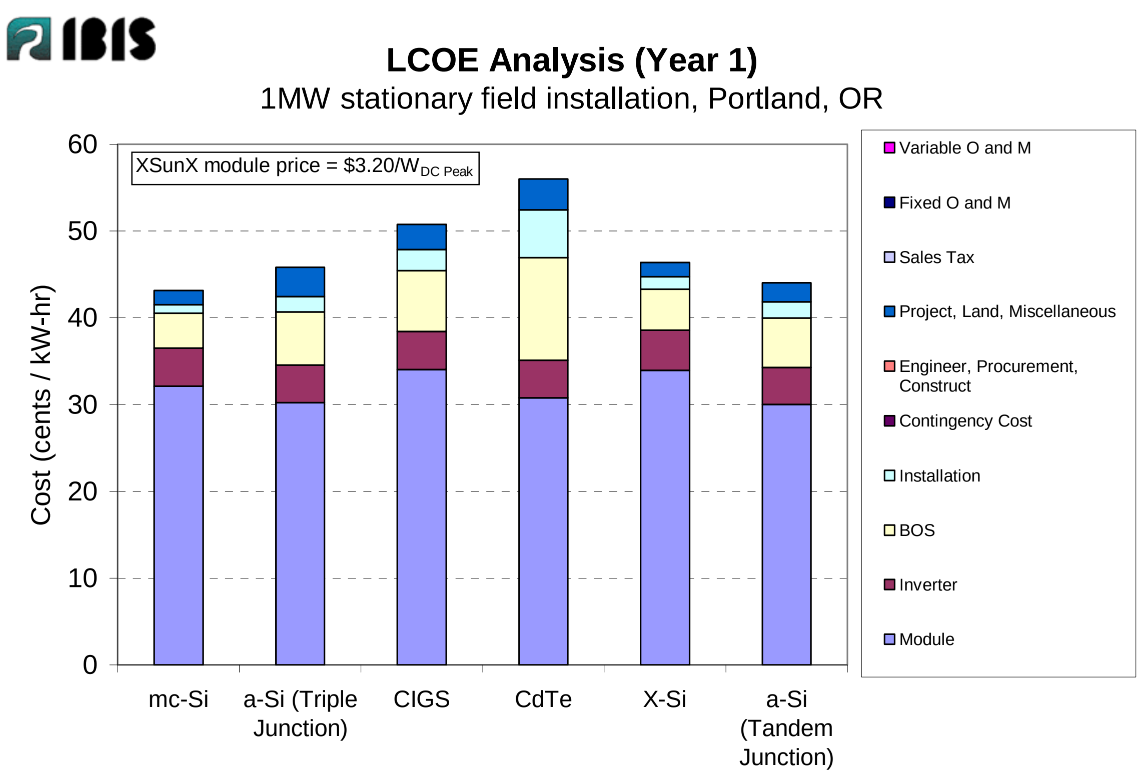

Figure 15 – LCOE: 1MW Portland, OR (fixed axis), $3.20/W XsunX module price

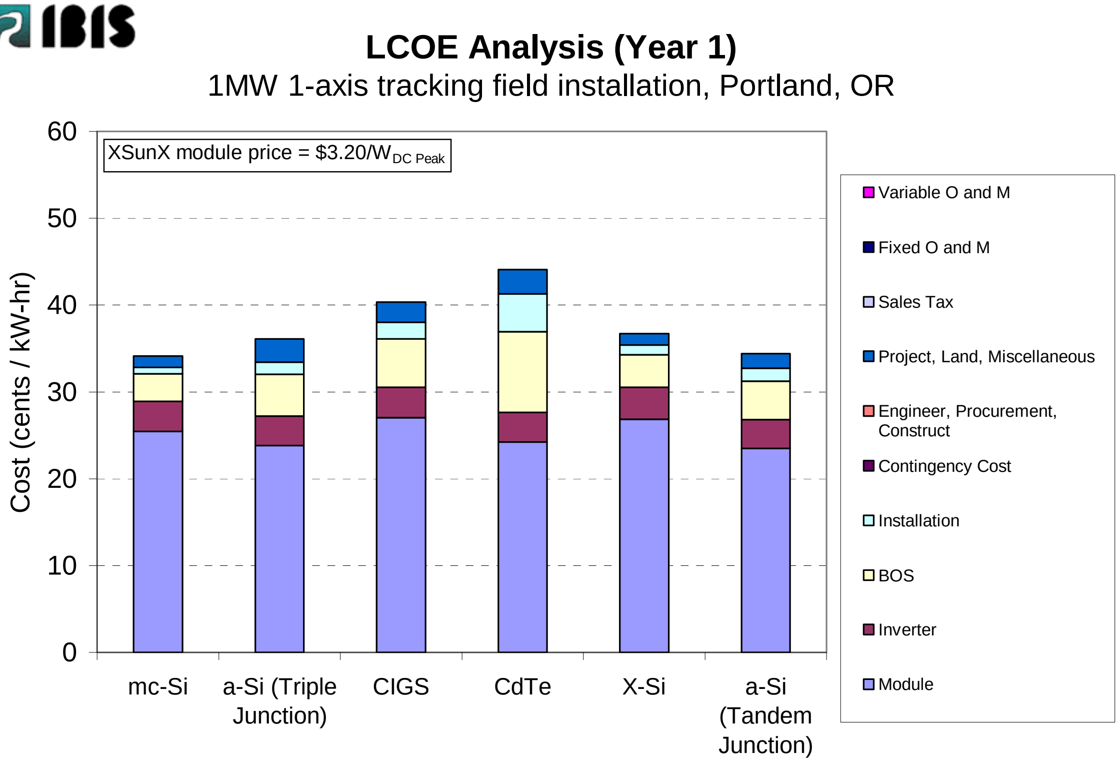

Figure 16 – LCOE: 1MW Portland, OR (1-axis), $3.20/W XsunX module price

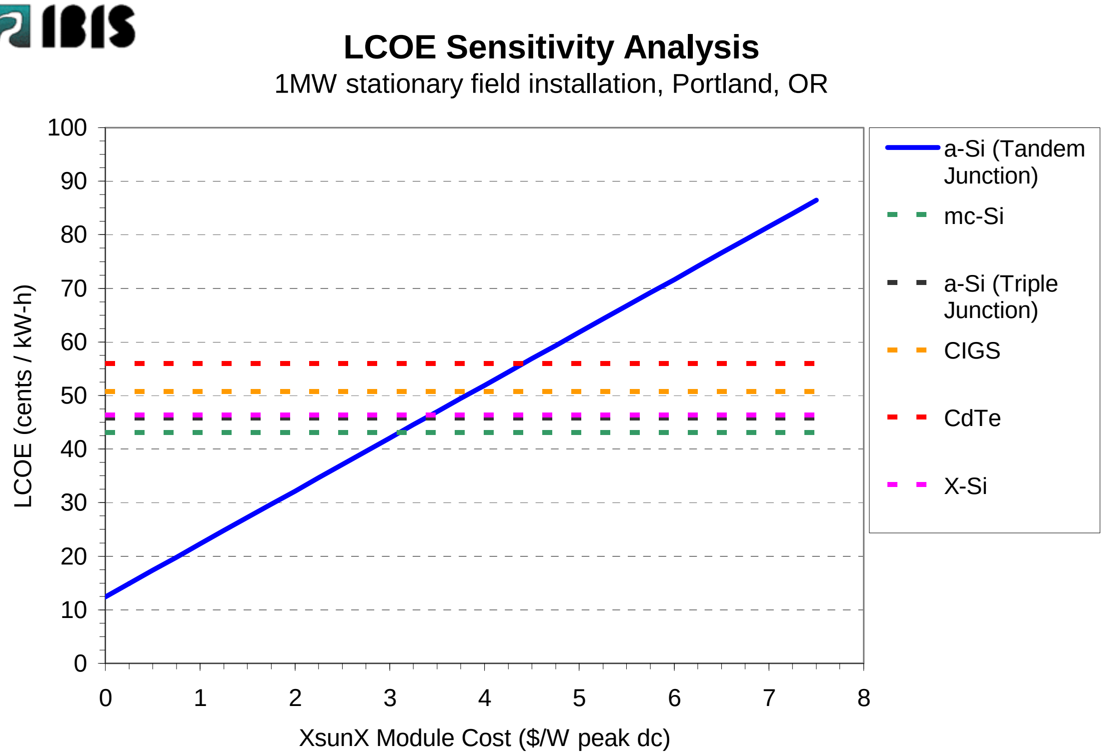

Figure 17 – LCOE Sensitivity: XsunX module price, 1 MW Phoenix, AZ (fixed axis)

Appendix: Interview Notes

<u>Note:</u> The following interview notes contain sensitive information and are not suited for broad redistribution. While the respondents spoke with IBIS knowing that their remarks might be passed on to the client, they were not given the opportunity to review these written notes and might find them, and their interpretation by IBIS, objectionable.

In response to the Ibis request above, XsunX has removed the interview data.